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Measurements of the $t\bar{t}$ production cross section at the Tevatron Run II CDF experiment using b-tagging

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We present measurements of the $t\bar{t}$ production cross section in b-tagged lepton + jets events from $p\bar{p}$ collisions at 1.96 TeV using the CDF detector at Fermilab. B-jets are tagged with either a secondary vertex algorithm, or a soft lepton tagger that identifies muons from B hadron semileptonic decays. With Tevatron Run II data, we estimate the $t\bar{t}$ signal fraction in two different ways: by estimating the various background contributions, and by fitting directly the leading jet transverse energy spectrum for the signal and background contributions. A subset of the sample, with two secondary vertex tagged jets, yields a production cross section consistent with the inclusive measurements. Results are consistent with a Standard Model $t\bar{t}$ signal and current measurements of the top quark mass.

Keywords: top; CDF; Tevatron

1. Introduction

The Tevatron (Run II) collides protons and anti-protons head-on at a center-of-mass energy of 1.96 TeV. In such collisions, the Standard Model (SM) predicts a $t\bar{t}$ production cross section of $\sigma_{t\bar{t}} = 6.7^{+0.7}_{-0.9}$ pb at $m_{\mathrm{t}} = 175\,\mathrm{GeV}/c^2$ [1]. Top quarks are expected to decay almost exclusively to a W boson and a b quark. When one W decays leptonically, the $t\bar{t}$ event contains a high transverse momentum lepton, missing energy from the unrecorded neutrino, and 4 high transverse momentum jets, 2 of which originate from b quarks. We use this decay channel to measure the total $t\bar{t}$ production cross section. A deviation from the predicted value would be an indication of new physics either in the production mechanism or in the top decay. We select events with an isolated electron E_T (muon P_T) greater than 20 GeV, missing E_T >20 GeV and at least 3 jets with E_T >15 GeV and $|\eta| < 2.0$. Finally, we require at least one jet in the event to be identified as a heavy flavor jet, either using a secondary vertex algorithm (SECVTX), or a soft lepton tagger (SLT) that identifies muons from B hadron semileptonic decays. The analyzes using SECVTX (resp. SLT) are based on $162\,\mathrm{pb}^{-1}$ (resp. $194\,\mathrm{pb}^{-1}$) of data. The CDF detector is described in detail elsewhere [2].

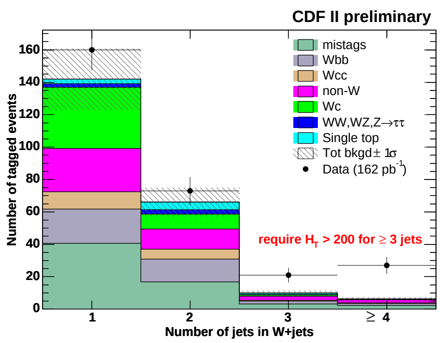

Fig. 1. Jet multiplicity of W+jets events tagged with the SecVtx algorithm in 162 pb^{-1} of data. The $H_T > 200$ GeV cut is only applied to events with three or more jets.

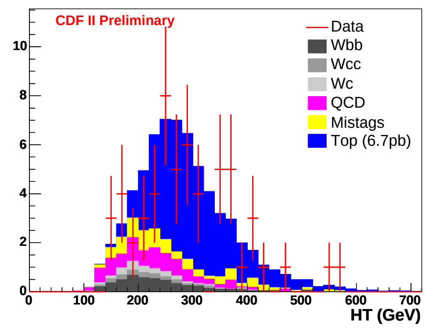

Fig. 2. H_T distribution of the candidate events compared to the expected backgrounds and $t\bar{t}$ signal.

2. Measurement with secondary vertex b-tagging.

We optimize the event selection by requiring that the total transverse energy in the event (H_T, the scalar sum of all jets E_T, lepton p_T, and missing E_T) be larger than 200 GeV. The SECVTX algorithm selects tracks within the jet with large impact parameter to reconstruct secondary vertices. Jets containing a secondary vertex more than 3σ away form the primary vertex (in the plane transverse to the beam) are identified as b-jets. After tuning the simulation on a control sample, the efficiency for tagging at least one jet in a $t\bar{t}$ event that passes all other selection requirements is (53 ± 4) %. The main sources of background are W + Heavy Flavor events, W + light jets events where one jet is wrongly tagged, and QCD events that fake a W signal; they are estimated with techniques that use both Monte Carlo and data control samples. We expect 13.8 ± 2.0 background events and observe 48 events in the data; we measure a cross section of $5.6^{+1.2}_{-1.1}(\text{stat.})^{+1.0}_{-0.7}(\text{syst.})$ pb. Fig. 1 shows the number of candidate events vs jet multiplicity together with the expected background contributions. Fig. 2 shows the H_T variable distribution of the candidates compared to the expected background and $t\bar{t}$ signal (normalized to 6.7 pb).

The sub-sample of events with at least two tagged jets contains 8 events, compared to an expected background of 0.9 ± 0.2 events, from which we measure a cross section of $5.4 \pm 2.2(\text{stat.}) \pm 1.1(\text{syst.})$ pb.

3. Measurement with SECVTX using a kinematic fit.

Instead of explicitly evaluating the contribution to the sample from backgrounds, one can extract the $t\bar{t}$ fraction by fitting some kinematic variable in the data. The leading jet E_T variable was chosen for this purpose. Template shapes for the background are evaluated from the data; the template shape for $t\bar{t}$ is from Monte Carlo.

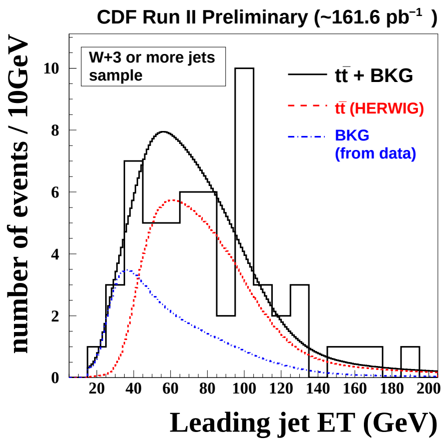

Fig. 3. Leading jet transverse energy of candidates in 162 pb^{-1} of data, together with fitted contribution from $t\bar{t}$ signal and background.

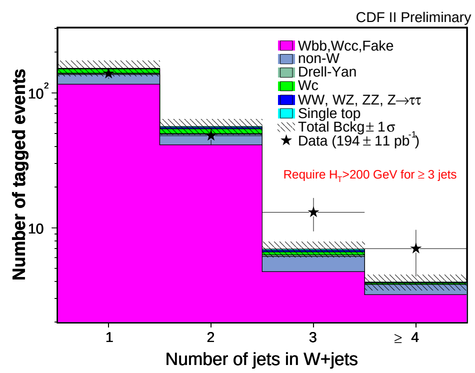

Fig. 4. Jet multiplicity of W+jets events tagged with the SLT algorithm in 162 pb^{-1} of data.

The fit (Fig. 3) measures a $t\bar{t}$ fraction of (67^{+13}_{-16}) %, leading to a cross section of $6.0^{+1.5}_{-1.8}(\text{stat.}) \pm 0.8(\text{syst.})\,\text{pb}$.

4. Measurement with soft muon b-tagging.

The muon SLT algorithm matches tracks in the central drift chamber with segments in the muon chambers. It uses a global χ^2 built from the matching distributions, to define a pseudo-likelihood variable, L, that separates muon candidates from background. A jet is considered "tagged" if it contains an SLT muon with $P_T > 3$ GeV/c, with L <3.5 and within ΔR <0.6 of the jet axis. Efficiency and fake rate are measured on control samples. Backgrounds are estimated with techniques similar to Sec. 2. We expect 11.6 ± 1.5 background events, and observe 20, and we measure a cross section of $4.2^{+2.9}_{-1.9}(\text{stat.}) \pm 1.4(\text{syst.})\,\text{pb}$. Fig. 4 shows the jet multiplicity of the candidates compared to the expected background.

References

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2. F. Abe, et al., *Nucl. Instrum. Methods Phys. Res.* A **271**, 387 (1988); D. Amidei, et al., *Nucl. Instrum. Methods Phys. Res.* A **350**, 73 (1994); F. Abe, et al., *Phys. Rev.* D **52**, 4784 (1995); P. Azzi, et al., *Nucl. Instrum. Methods Phys. Res.* A **360**, 137 (1995); *The CDFII Detector Technical Design Report*, Fermilab-Pub-96/390-E